NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(SET-088)TP/541

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STO TECHNICAL REPORT **TR-SET-088**

Littoral Infrared Ship Self Defence Technology Studies

(Autodéfense côtière infrarouge des navires études technologiques)

Final Report of Task Group SET-088/RTG-51.

Published May 2014

Distribution and Availability on Back Cover

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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Published May 2014

ISBN 978-92-837-0202-3

Table of Contents

List of Figures/Tables

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Littoral Infrared Ship Self Defence Technology Studies

(STO-TR-SET-088)

Executive Summary

This Task Group addressed the following aspects of littoral ship self-defence:

1) The detection of anti-ship missiles in littoral environments;
2) The detection of small surface targets in littoral environments;
3) The upgrade and validation of the Naval Threat Countermeasure Simulator modeling and simulation code to include decoys and missile seekers;
4) Additional upgrade and validation of the SHIPIR modeling and simulation code;
5) The development of infrared ship signature specification guidelines; and
6) The study of infrared signature reduction techniques.

During its tenure, SET-088 organized a total of five scientific Workshops, where subject-matter experts from all the member countries (as well as other NATO and PfP Nations) were invited to give technical talks and participate in scientific debate and discussions.

Research on infrared ship signatures was a major area of collaboration for SET-088. This was a significant portion of each country's "Country Report" that each country presented at each meeting. Most of the member countries planned and executed national trials on IR ship signatures.

Infrared propagation research was another focus of the Task Group. The major activities for IR propagation research involved the execution of the VAMPIRA trial with SET-056 (Integration of Radar and Infrared Ship Self Defence), the analysis of that data, comparison to the Canadian IRBLEM model, the planning of the SET-088 trial SAPPHIRE and another round of IRBLEM validation.

The primary achievement of SET-088 was the execution and analysis of a major trial called SAPPHIRE **(S**hip and **A**tmospheric **P**ropagation **PH**enomenon **I**nfra**R**ed **E**xperiment.) The NATO SAPPHIRE trial was conducted in the Chesapeake Bay, USA in June 2006. Eleven infrared test teams from 10 different NATO Nations participated (Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Poland, UK and US).

Five different types of tests were performed:

- IR ship signature;
- IR ship turbine signature;
- Speed boat / jet ski detection;
- IR point source detection; and
- IR/visible refraction/scintillation runs.

The trial represents "state-of-the-art" techniques in trial planning and execution. This was only possible by combining both the experience of several countries' IR measurement teams and their key instrumentation.

Autodéfense côtière infrarouge des navires études technologiques

(STO-TR-SET-088)

Synthèse

Ce groupe de travail a traité des aspects suivants de l'autodéfense côtière infrarouge :

1) La détection des missiles antinavires sur le littoral ;
2) La détection des petites cibles de surface sur le littoral ;
3) L'amélioration et la validation de la modélisation et du code de simulation du Simulateur de Contre-mesures de la Menace Navale afin de pouvoir inclure des leurres et des autodirecteurs de missiles ;
4) Une amélioration et une validation supplémentaire de la modélisation et du code de simulation du SHIPIR ;
5) Le développement des directives de spécification de la signature infrarouge des navires ; et
6) L'étude des techniques de réduction de la signature infrarouge.

Durant sa période d'activités, le SET-088 a organisé un total de cinq ateliers scientifiques, où des experts en la matière de tous les pays membres (aussi bien de l'OTAN que des pays du PpP) ont été invités à faire des déclarations techniques et à participer à des débats et des discussions.

La recherche sur la signature infrarouges des navires a été un domaine de collaboration important au sein du groupe SET-088. Ce fut une partie significative de chaque "Rapport National" présenté à toutes les réunions. De nombreux pays membres ont planifié et exécuté des essais nationaux sur les signatures IR des navires.

La recherche sur la propagation infrarouge a été un autre sujet d'intérêt pour le groupe de travail. Les activités principales de la recherche sur la propagation IR ont concerné l'essai VAMPIRA avec le groupe de travail SET-056 (Intégration du Radar et de l'Autodéfense Infrarouge des Navires), l'analyse de ces données, la comparaison avec le modèle Canadien IRBLEM, la planification de l'essai SAPPHIRE du groupe SET-088 et une autre phase de validation IRBLEM.

La première réussite du SET-088 a été l'exécution et l'analyse d'un essai important appelé SAPPHIRE (**S**hip and **A**tmospheric **P**ropagation **PH**enomenon **I**nfra**R**ed **E**xperiment – Expérimentation Infrarouge du PHénomène de Propagation des Navires et Atmosphérique.) L'essai SAPPHIRE de l'OTAN a été conduit dans la Baie de Chesapeake, Etats-Unis en juin 2006. Onze équipes d'essais infrarouges de 10 pays de l'OTAN y ont participé (Canada, Danemark, France, Allemagne, Italie, Pays-Bas, Norvège, Pologne, Royaume-Uni et Etats-Unis).

Cinq types d'essais différents ont été effectués :

- Signature IR des Navires ;
- Signature IR de la Turbine des Navires ;
- Détection d'une Vedette/d'un Jet Ski ;
- Détection IR d'un Point Source ; et
- Séries de Réfractions/Scintillations IR/Visibles.

Cet essai représente “l’état de l’art” dans les techniques de planification et d’exécution des essais. Ceci n’a pu être réalisé qu’en associant l’expérience des équipes de mesures IR de plusieurs pays et leurs instrumentations clés.

Chapter 1 – INTRODUCTION

Research Study Group No. 5 (RSG.5) titled "Anti-Ship Infrared Missile Characteristics, Backgrounds, and Countermeasures" was initiated in June 1968. It was modified in October 1984 to become RSG.5 on Maritime Infrared Targets and Background Signatures: Measurements and Characterization. The RSG.5 effort concentrated on the improvement of methodologies associated with target and background measurements. After completion of a number of common trials, the Task Group decided to emphasize work on ship and background model comparison and validation.

In October 1994, RSG.5 agreed to assume responsibility for some of the tasks of RSG.9 on "Signal Processing Techniques for the Detection of Point Targets in IR Surveillance", upon dissolution of that group. RSG.5's tasks expanded to include projects of infrared surveillance of air targets for self defence, including the assessment of the detection range of such sensors against point targets.

When RSG.8 on "Atmospheric Propagation Effects on Electro-Optical Systems" was closed in 1996, RSG.5 assumed the responsibility for some of its tasks, including field experiments to understand the effects of atmospheric phenomena such as scintillation and refraction on the ability of infrared sensors to detect targets, and the validation of models on the effects of the atmosphere on Electro-Optical (EO) sensors.

With the merging of the NATO Defence Research Groups and the Advisory Group for Aerospace Research and Development into the Research and Technology Agency (RTA) effective 1 January 1998, RSG.5 ceased to exist. Under the RTA Sensor and Electronics Technology (SET) Panel, RSG.5 was re-established as Task Group Number 06 (TG-06) with the same title and Terms of Reference as RSG.5 through 31 December 1999, at which time TG-06 ended.

Task Group Number 16 (TG-16), titled "Infrared Measurements and Modelling for Ship Self Defence", started on 1 January 2000 and will end on 31 December 2003, and generally followed the objectives of the previous RSG.5/TG-06. Efforts of TG-16 focused on infrared modeling of military ships and sea/sky backgrounds, radiation transfer in a marine environment, detection of point targets.

TG16 efforts focused on "blue-water" naval scenarios. Little effort was made to study the effects of the littoral environment on ship self defence, which will be the focus of the new Task Group.

This Task Group will address the following aspects of littoral ship self defence:

1) The detection of anti-ship missiles in littoral environments;
2) The detection of small surface targets in littoral environments;
3) The upgrade and validation of the Naval Threat Countermeasure Simulator modeling and simulation code to include decoys and missile seekers;
4) Additional upgrade and validation of the SHIPIR modeling and simulation code;
5) The development of infrared ship signature specification guidelines; and
6) The study of infrared signature reduction techniques.

Chapter 2 – WORKSHOPS

SET-088 organized a total of 5 scientific Workshops, where subject matter experts from all the member countries (as well at other NATO and PfP Nations) were invited to give technical talks and participate in scientific debate and discussions. Four of the Workshops were on infrared ship signature modelling and those took place during the Spring 2004, Spring 2005, Spring 2006 and Spring 2007 meetings. One Workshop was held on infrared sea surface modelling, which was held at the Fall 2007 meeting. These workshops provided a unique and valuable forum to share the results of scientific research in all of the participating Nations.

Chapter 3 – SHIP SIGNATURE RESEARCH

Research on infrared ship signatures was a major area of collaboration for SET-088. This was a significant portion of each Nations' "Country Report" that was presented at each meeting. Most of the Member Nations planned and executed national trials on IR ship signatures. When this occurred, each Nation shared as much of the technical results as possible (within security constraints) and universally shared lessons learned with respect to test execution, measurement results, signature modelling techniques and individual county work on model validation.

Most of the Member Nations uses the same IR signature model, ShipIR. This was an efficient mechanism for scientific data exchange. Some Nations use their own country-developed model and some use both types. This provided an opportunity for cross-validation of models. This work was particularly fruitful, since different models have different strengths and weaknesses. Through comparison to field data, the Task Group was able to discern which models were better at predicting different phenomenology and this hastened the improvement of all models involved.

Chapter 4 – PROPAGATION RESEARCH

The major activities for IR propagation research involved the execution of the VAMPIRA trial with TG-32, the analysis of that data, comparison to the Canadian IRBLEM model, the planning of the TG-51 trial SAPPHIRE and another round of IRBLEM validation.

The first trial was with TG-32 called VAMPIRA (Validation Measurement for Propagation in IR and Radar) Trial. The objective of the test was the collection of data for validation of IR and radar models. The test campaign occurred during the March 25 – April 6, 2004 time period. Test participants included members of TG-32 and TG-51 including Germany, Denmark, United Kingdom, Netherlands, France, USA, and Canada. The test was considered to be very successful with IR and RF data collected in super-refractive conditions and RF data collected for sub-refractive conditions. The final report was completed in August 2005.

One finding from preliminary data reduction is that there is a need for data collected with warmer water and air temperatures and higher relative humidity conditions. Lessons learned from this trial factored into the planning of the SAPPHIRE trial in June 2006.

Chapter 5 – TEST CAMPAIGNS

5.1 INTRODUCTION AND BACKGROUND

The NATO Science Panel SET-088/RTG-51 has the charter to investigate infrared research topics relating to Littoral Ship Self Defence. Specifically, the two main research areas for TG-51 are:

1) Low-altitude maritime IR propagation phenomenology; and
2) Ship signature and detectability.

Several multi-national trials have been conducted in the past. Most propagation trials have been conducted in cold waters, with predominantly negative Air-Sea Temperature Differences (ASTD) resulting in sub-refraction. New data was needed with warm water and positive ASTD in order to understand the phenomenology and validate predictive models, such as the IR Boundary Layer Effects Model, IRBLEM. Previous ship signature trials have lacked sufficient "ground truth" to be of use for rigorous model validation.

The NATO SAPPHIRE trial was conducted in the Chesapeake Bay in June 2006. Eleven infrared test teams from 10 different NATO Nations participated (Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Poland, the United Kingdom and the United States).

Five different types of tests were performed:

- IR ship signature;
- IR ship turbine signature;
- Speed boat / jet ski detection;
- IR point source detection; and
- IR/visible refraction/scintillation runs.

The full-ship signature and turbine signature runs were conducted for the purposes of signature model validation. Speed boat and Jet Ski IR detection trials were run to provide data for susceptibility studies against asymmetric threats to ships. The point-source detection runs simulated a low-flying ASCM; these data are valuable in assessing the performance of shipboard IR Search and Track, IRST, systems. Finally the refraction/scintillation runs (continuous 24 hours a day) were run to validate propagation models for the marine boundary layer.

In addition to the continuous atmospheric runs, a total of 56 runs were executed over a two week period. Extensive ground truth was measured as well. Multiple meteorological stations measured weather over the entire operating area. Radiosonde balloons were launched to characterize the upper atmosphere. Additionally, Global Positioning Systems (GPS) provided reliable time-space-position information.

The data from this trial has been reduced and analyzed. A summary of the data from the five types of runs will be presented.

5.2 OBJECTIVE

The main overarching objective of this trial was to collect data of sufficient quality to validate both the ShipIR [1] and refraction/scintillation models, such as IRBLEM [2] in littoral areas under conditions of warm sea temperatures.

The objectives for the "maritime target signature" portion of the trial were:

1) To collect IR signature data of the Canadian research vessel CFAV Quest (Figure 5-1) along with sea/sky radiance for subsequent validation of the ShipIR model;
2) To collect IR signature data on smaller craft, such as a speed boat and a jet ski, which will enable NATO navies to estimate the detection range of small asymmetric threats to naval ships by their Forward Looking Infrared Radiometers, FLIRs, or IRST systems; and
3) Collect data on IR ship decoys, to enable assessment of their effectiveness in protecting NATO warships against ASCMs.

Figure 5-1: Photograph of CFAV Quest.

The objective of the propagation experiment was to collect data on refraction effects, turbulence and scintillation in both visual and IR wavebands. The aim was to have a sufficient dataset for warm waters to validate refraction/scintillation models under these conditions.

5.3 PARTICIPANTS AND LOCATION

The trial was conducted at the Naval Research Laboratory's Chesapeake Bay Detachment (CBD) field site on Chesapeake Bay. The overall test window was from 19 – 30 June 2006. Twelve test teams from 10 NATO Nations (Table 5-1) were set up at one of three shore sites. One of the teams (Italy) performed ship plume measurements from the Quest research ship during the first week. The low site had an elevation of approximately two meters above Mean Sea Level (MSL) and the two high sites were located approximately 30 meters MSL on top of a cliff overlooking the shore.

Table 5-1: SAPPHIRE Test Participants.

Country	People	Location
US-NRL	3	High Site #1
US-NSWC	3	High Site #2
Germany	3	Low Site
Canada	1	Quest and High Site #1
France	2	High Site #1(1st week)
Italy	2	Quest (1st week)
Norway	8	Low Site
UK	3	Low Site
Netherlands	2	Low Site
Denmark	3	Low Site
Poland	1	Low Site
South Africa	2	Guest Team-Low Site
Australia	2	Observers

5.4 TRIAL OVERVIEW

5.4.1 Ship Signature

Quest runs were primarily north-south and SE-NW tracks (Figure 5-2). Data were collected at a range of approximately 1.5 km (referred to as the “measurement point” and marked by the red circle that the arrows are pointing to in Figure 5-3) at two ship speeds, of 8 and 12 knots. In order to achieve thermal equilibrium, the Quest was on a constant course and at a constant speed for more than 30 minutes prior to reaching the measurement point.

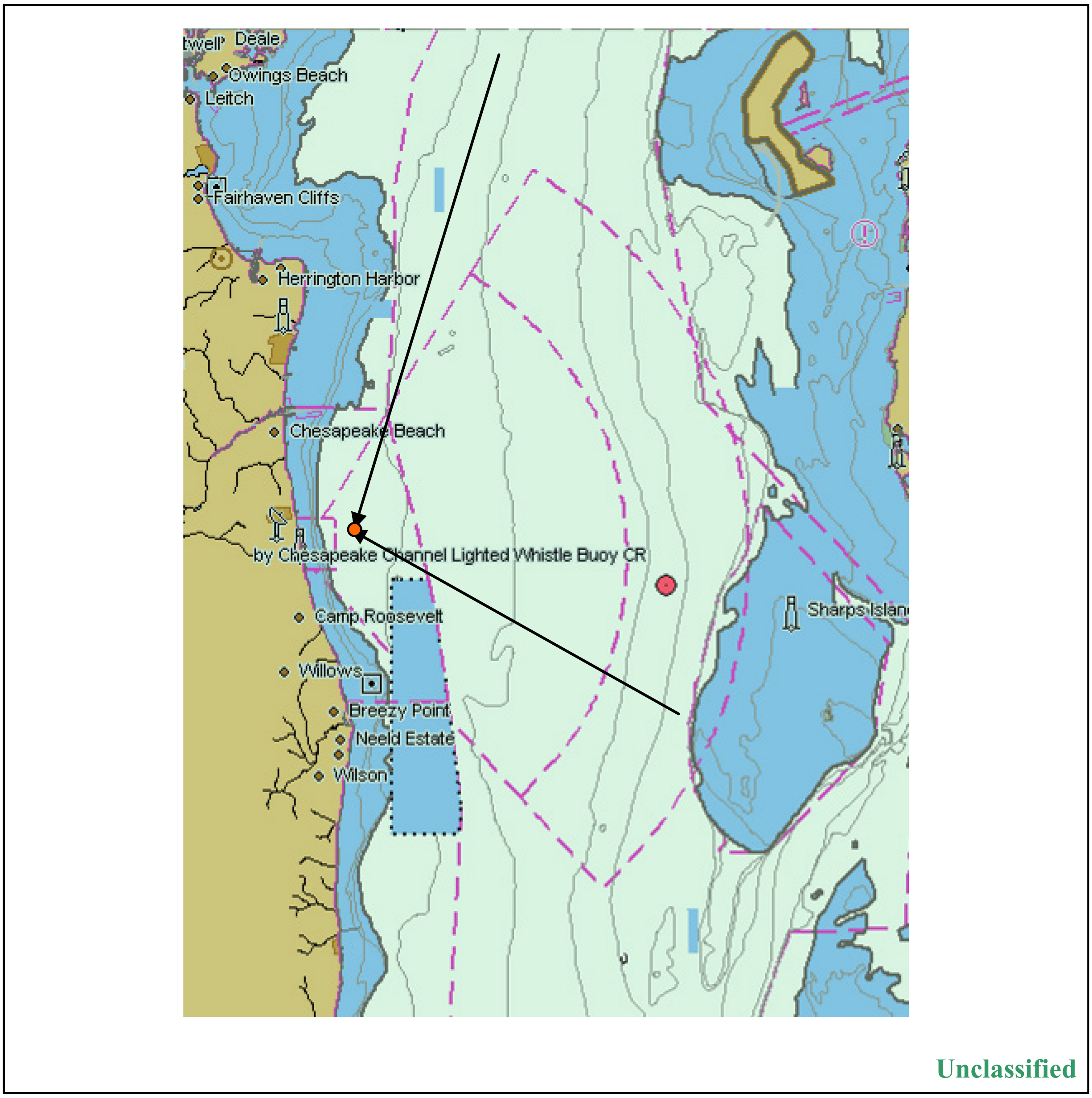


Figure 5-2: Quest Tracks: SE to NW and North to South.

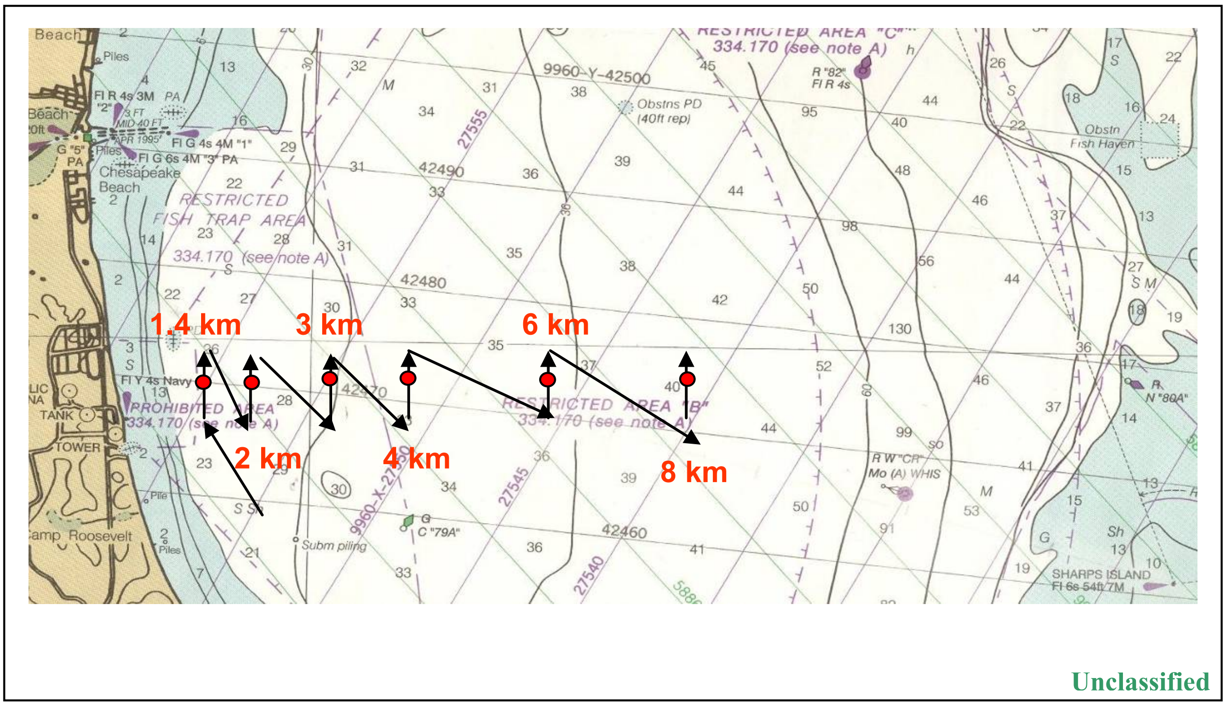


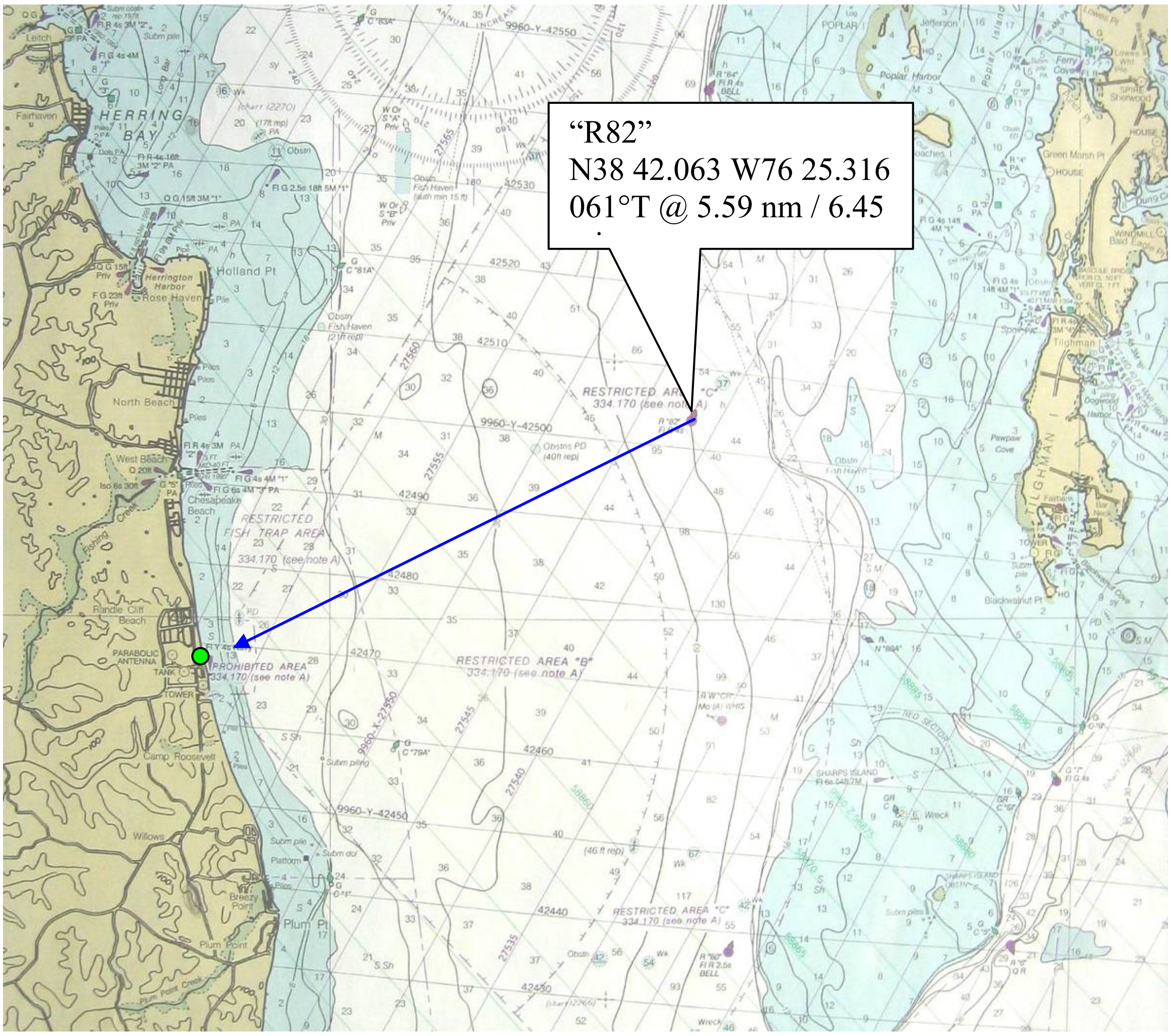
Figure 5-3: Plume Runs.

5.4.2 Plume Signature

The objective of plume signature measurements was to accurately measure the IR signature of the Quest's turbine plume at various fixed ranges: 1.4, 2, 3, 4, 6, and 8 km (Figure 5-3). The Italian team made close-up plume measurements from on board the Quest.

5.4.3 Small Boat Detection

Small boats were measured on radial inbound courses from a buoy 5.6 nautical miles away (Figure 5-4, blue arrows). The objective of this test was to measure the IR detection range of an inbound craft (and potentially FLIR detection range). Both a jet ski and a small speed boat (Hunter) were tested (Figure 5-5 and Figure 5-6). A portable GPS logging unit was installed on each target craft to record time-space-position information.



Unclassified

Figure 5-4: Shore Site (Green Circle); Small Craft Tracks (Blue Arrow).

Unclassified

Figure 5-5: Photo of the Jet Ski.

Unclassified

Figure 5-6: Hunter Boat.

5.4.4 Decoy Signature

The Kilgore TALOS IR ship decoy (Figure 5-7) was deployed from NRL's landing craft. The landing craft (referred to as the LCM) was stationary approximately two kilometers east of the shore site. The decoy launch azimuth was determined before the launch by the wind direction at the time of each run. IR signature was measured as a function of time. A total of three decoys were fired.

Unclassified

Figure 5-7: Example Photograph of the TALOS Decoy.

5.4.5 Propagation

5.4.5.1 Refraction and Turbulence

IR cameras and visible-band high-speed cameras were set up at the shore site overlooking Chesapeake Bay. The cameras observed a set of lights installed on Tilghman Island, which was 16.2 km to the east (Figure 5-8 and Figure 5-9.) The lights were set up at four different heights; three on the tower, ranging from 14 to 31 meters above Mean Lower Low Water (MLLW) and the fourth was mounted near the ground at approximately 5.8 meters MLLW. The aim of the experiment was to study the resolution degradation caused by atmospheric turbulence and the angular deviation caused by refraction.

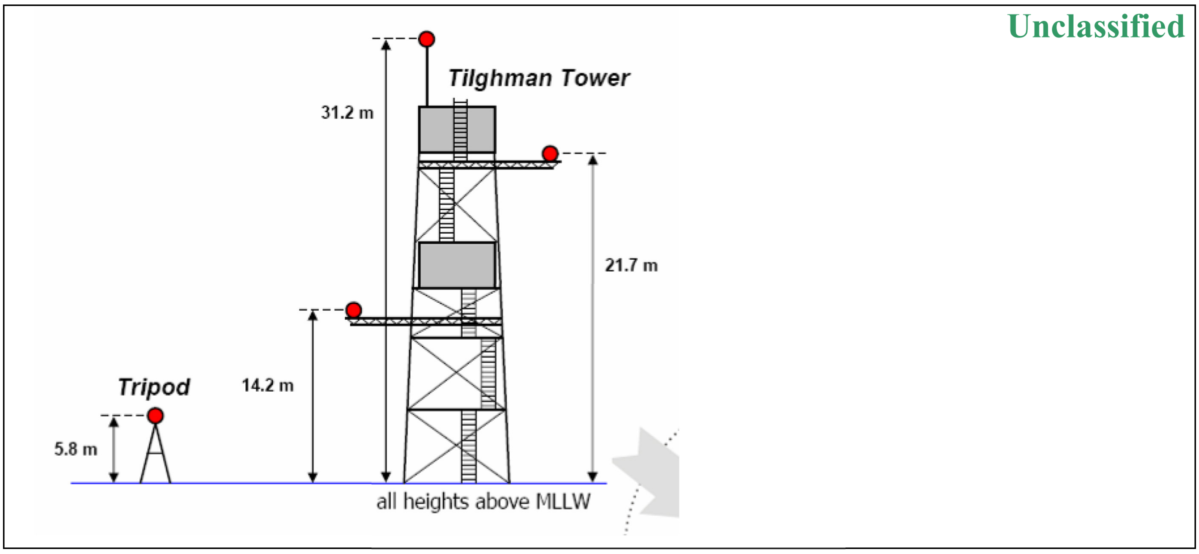


Figure 5-8: Diagram of the Lights Mounted on Tilghman Tower.

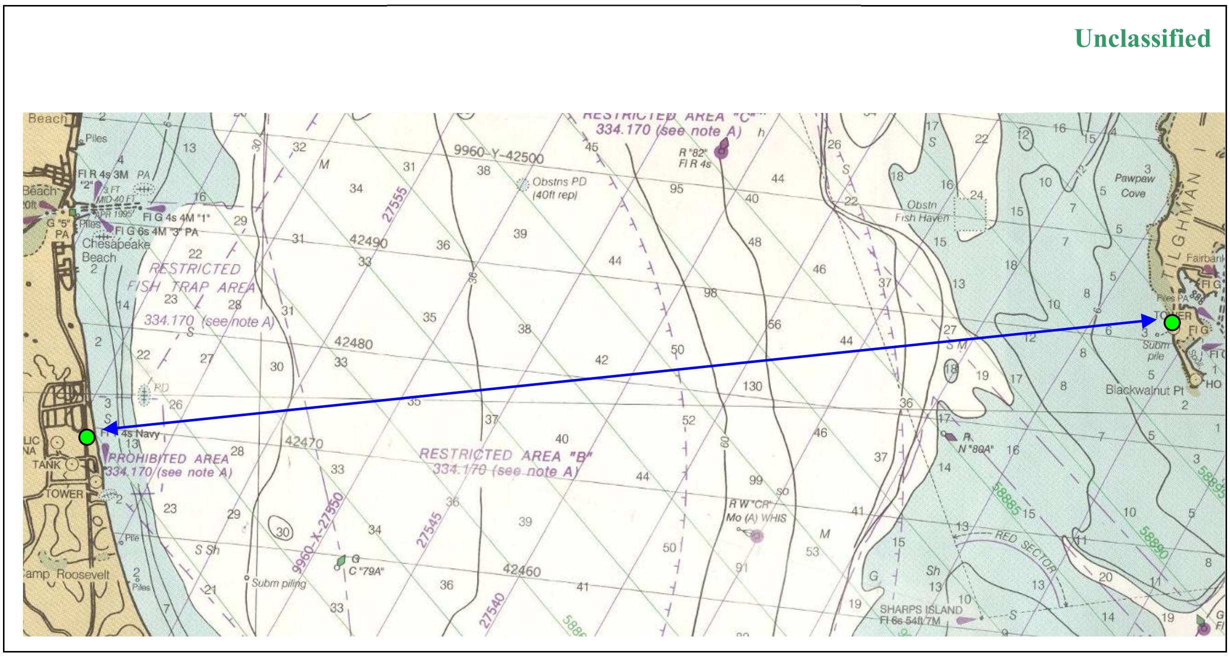


Figure 5-9: Chart Showing Path Between CBD and Tower at Tilghman Island.

5.4.5.2 Detection Ranges

An IR source was mounted on the Hunter boat (Figure 5-10) simulating a low flying ASCM. The height was approximately four meters above the water level. The source was pointed aft since all of the runs were outbound. The Hunter boat remained on an outbound course until detection was lost by all test teams. The IR-imagers recorded sequences of the boat runs. The aim was to analyze maximum detection ranges under various atmospheric conditions and to compare the measurement results with predictions of the propagation model. The Hunter took a course of approximately 105 deg. true, which enabled a long maximum range, Figure 5-11.

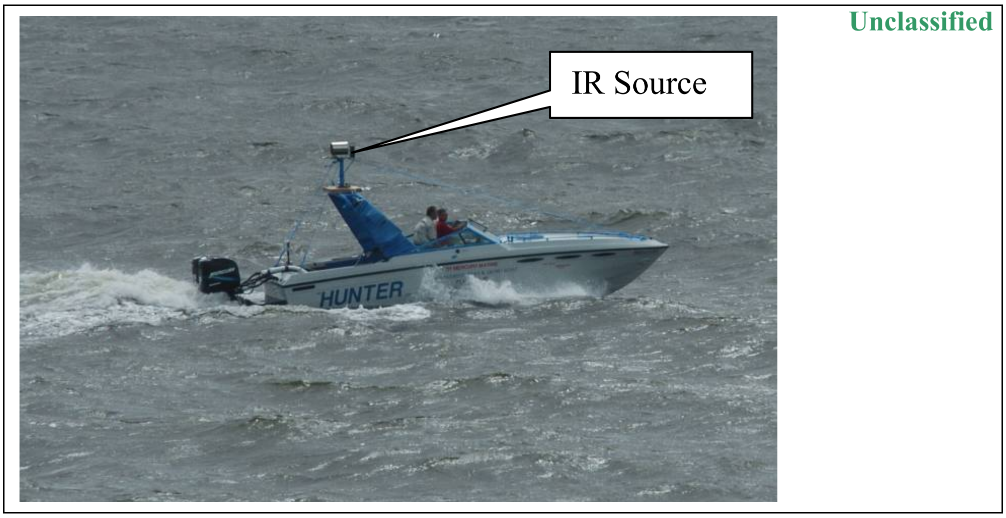


Figure 5-10: IR Heat Source Used for Detection Experiments.

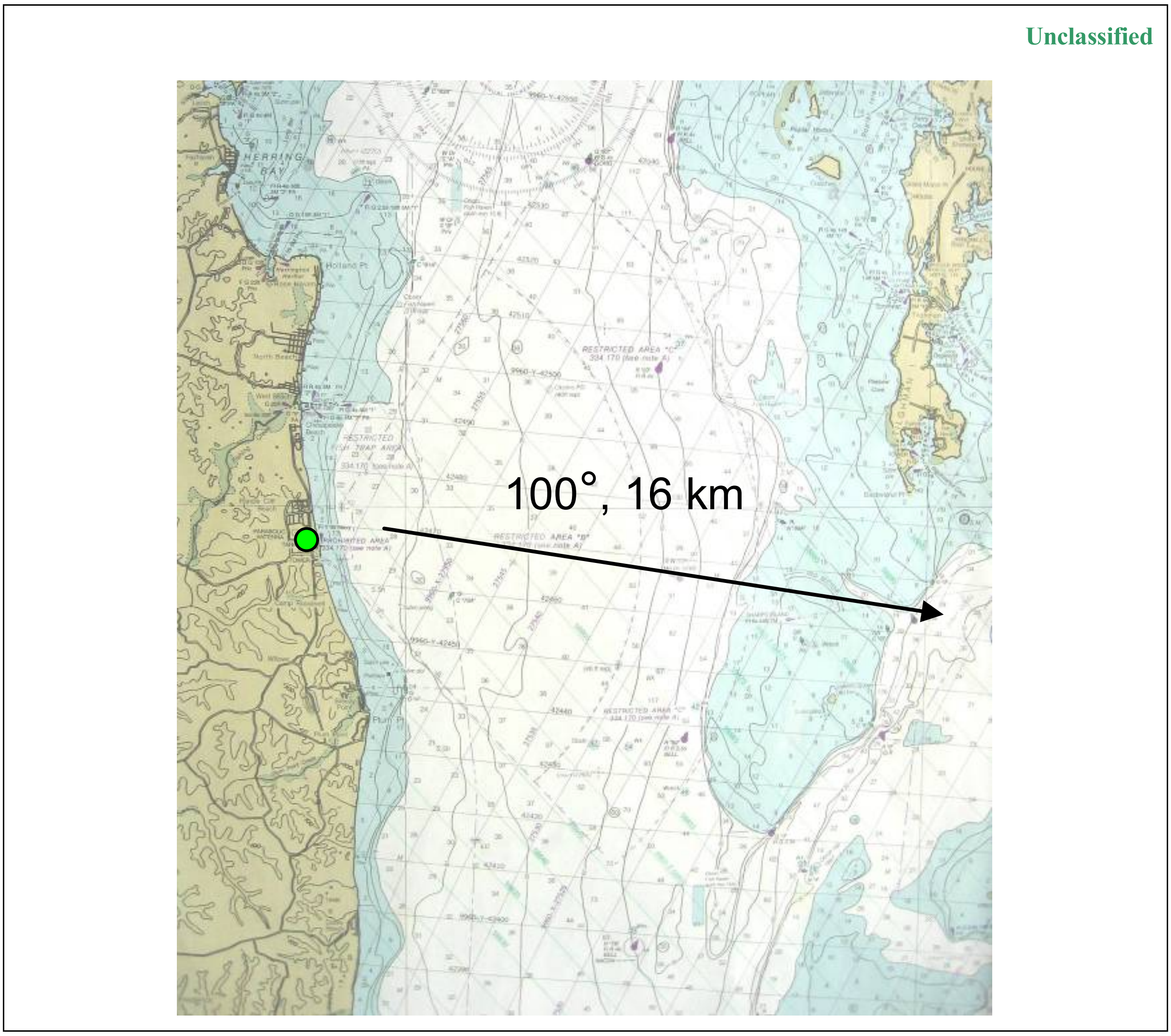


Figure 5-11: A 16 km Line-of-Site at a Heading of 100 Degrees.

5.5 SUMMARY AND RESULTS

A summary of the various types of runs is shown in Table 5-2.

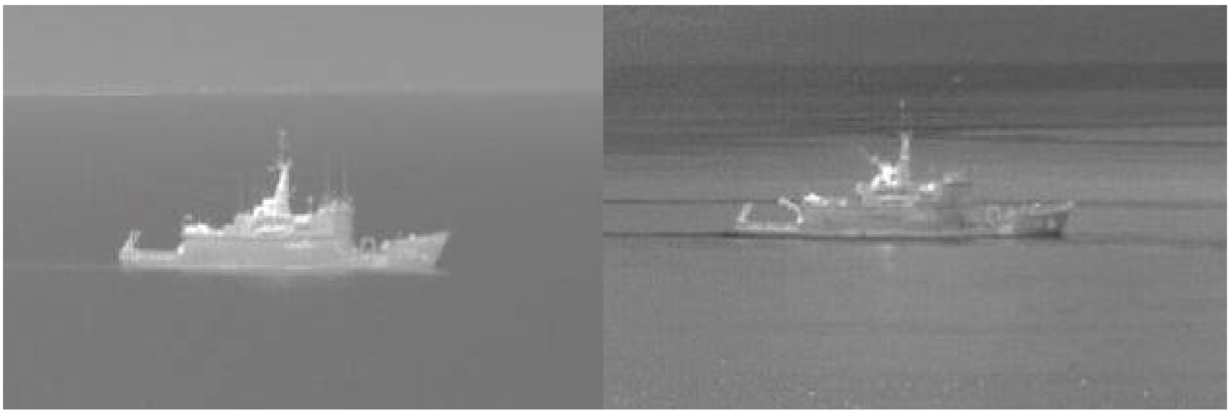
Table 5-2: Run Summary by Type.

Run Type	Number of Runs Executed
IR Ship Signature	20
IR Ship Turbine Signature	3
Speed Boat / Jet Ski Detection	20
IR Point Source Detection	12
IR Ship Decoy Signature	3
IR/Visible Refraction/Scintillation	Continuous for 12 days

5.5.1 IR Ship Signature

Of the 20 runs, ten had uniform cloud cover (seven clear and three overcast) making them ideal for model validation. The remaining ten runs had partial cloud cover, which can be used for the validation of the new “structured sky” feature in ShipIR. See Figure 5-12. The apparent contrast intensity ranged from -10 to 170 W/sr in the MW band and 90 to 450 W/sr in the LW band.

Unclassified



(a) (b)

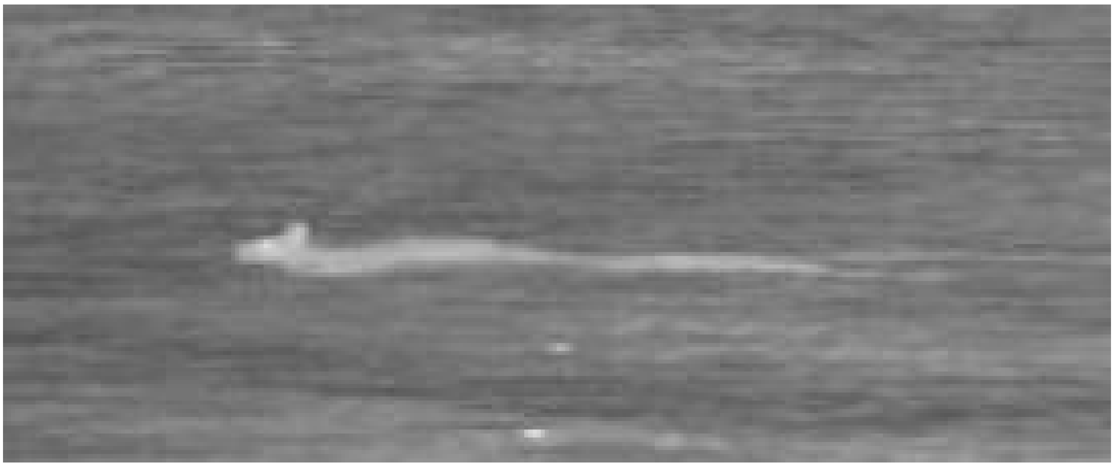
Figure 5-12: MW Band Images of the Quest: (a) Clear Skies; (b) Overcast Conditions.

5.5.2 IR Ship Turbine Signature

The three turbine runs were very valuable because the turbine engine of the Quest was well characterized. Many countries collected spectrally-banded imagery, and both the US and Norwegian teams measured spectral data with high-resolution FTIR instruments.

5.5.3 Speed Boat / Jet Ski Detection

These runs were executed over two separate days, 22 and 23 June, Figure 5-13. The test conditions of interest are cloud cover (and its effect on target signature) and air-sea temperature difference (and its effect on propagation). On the 22nd, the skies were clear, resulting in high solar loading and high signature. The ASTD was also high, ranging from +1 to +3 °C. On the 23rd, the skies were overcast and the ASTD was fairly low, around +1°C. Both the speed boat and the jet ski ran parallel courses at the same speed. The speed varied from 18 to 37 knots. Both inbound and outbound detection runs were executed.



Unclassified

Figure 5-13: IR Image of a Jet Ski.

5.5.4 IR Point Source Detection

For this type of run, the signature of the source was constant, so the main variable was ASTD and how it affects propagation. The IR source had a constant temperature of 200°C and had a radiant intensity of about 2 W/sr in the MW band and 4 W/sr in the LW band. Two runs were executed on 27 June and 10 runs on 28 June. The ASTD varied from -1.2 to +0.1 °C over these runs and in the MW band, the detection range varied from 12.8 to 18.5 km. These values should be compared to the geometric horizon of 15.7 km. The difference between the detection range and the geometric horizon correlates very well with ASTD. When the ASTD went positive, the super-refraction resulted in "over-the-horizon" detection. Thus for a target of just a few watts, the detection in the MW band was driven by second order propagation effects.

5.5.5 IR Ship Decoy Signature

Three Kilgore "Talos Autofire" rounds were deployed on 29 June, Figure 5-14. Each round was comprised of five sub-munitions. Radiometric imagery was collected in both MW and LW bands. Spectral signatures from 2 – 5 µm were collected with FTIR instruments. The details of the decoy signature have been reported previously, at the 2006 MSS IRCM [3], but the general decoy properties are shown in Table 5-3.

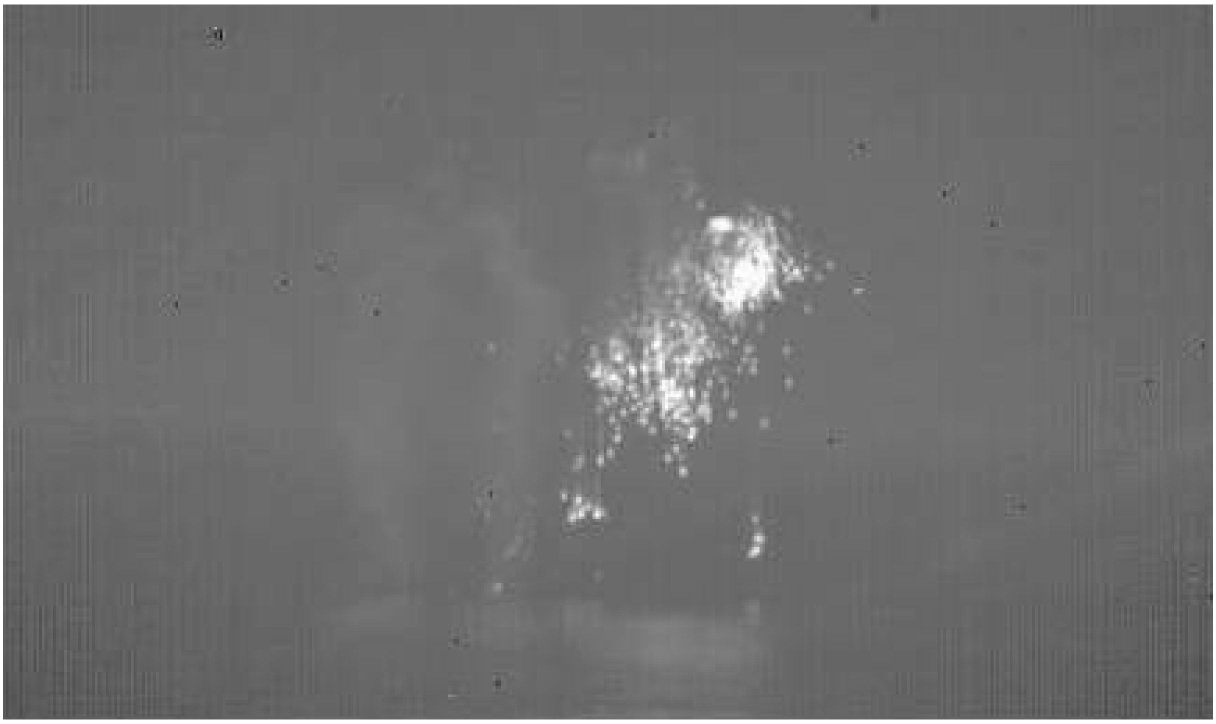


Figure 5-14: IR Image of the TALOS Round.

Table 5-3: Ship Decoy IR Characteristics.

Parameter	Value/Range
MW Radiant Intensity	5 – 6 kW/sr
LW Radiant Intensity	11 – 14 kW/sr
Total Burn Time	~ 45 sec.
Effective Emitting Area	400 – 500 m^2

5.5.6 IR/Visible Refraction/Scintillation

High-resolution imagery of the lights on Tilghman Island was collected continually from 19 – 29 July. The main weather parameter of interest is the ASTD, which varied over this period from -4.7 to +4.8 °C. A typical sequence of MW images is show in Figure 5-15. The apparent angular elevation of each light changes from 18:40 hours of one day, overnight, until 09:15 the next morning. This effect is caused by the natural diurnal change in ASTD. As the conditions changed from sub-refractive to super-refractive, the angular deviations for each light were measured and compared to IRBLEM model predictions. The prediction accuracy of the model was shown to be very good, which was only possible due to the superior ground truth, specifically the air temperature profile measured from a buoy deployed for this trial. The results of this part of the trial are unclassified and have been reported extensively in the unclassified literature [4].

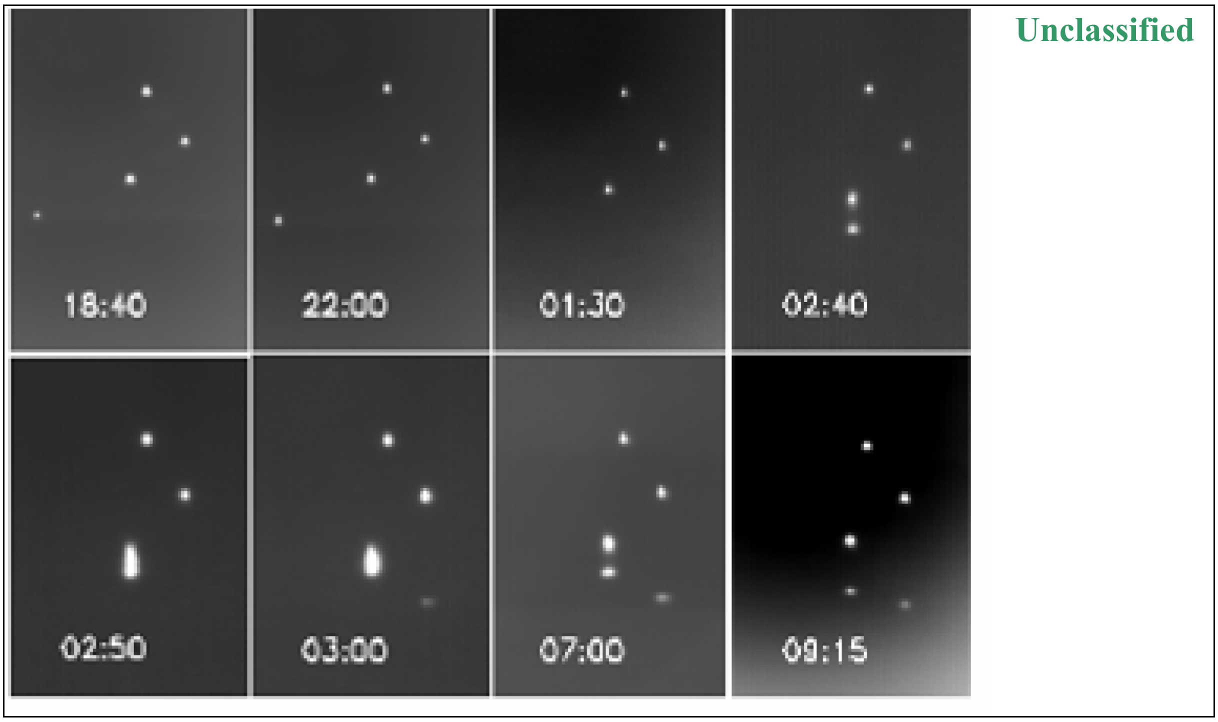


Figure 5-15: MW IR Images of the Tower Lights Overnight.

5.6 DATA QUALITY ASSESSMENT

The quality of the dataset can be judged by both the measurement accuracy of the individual data points and the variation of conditions under which the data were collected. By both criteria, the quality of this dataset is judged to be very high. Also, additional measures were taken to improve the overall quality of the data. These measures were "lessons learned" from previous joint NATO IR trials and are summarized below:

- Quantified measurement accuracy of IR imaging radiometers;
- Common calibration and data reduction procedures for imaging radiometers;
- Redundant TSPI/GPS;
- "Alignment' of multiple weather stations by co-located measurement (Figure 5-16); and
- Multiple weather stations on both shores, onboard ship, and from buoys (Figure 5-17).

Figure 5-16: Weather Station "Alignment" Run.

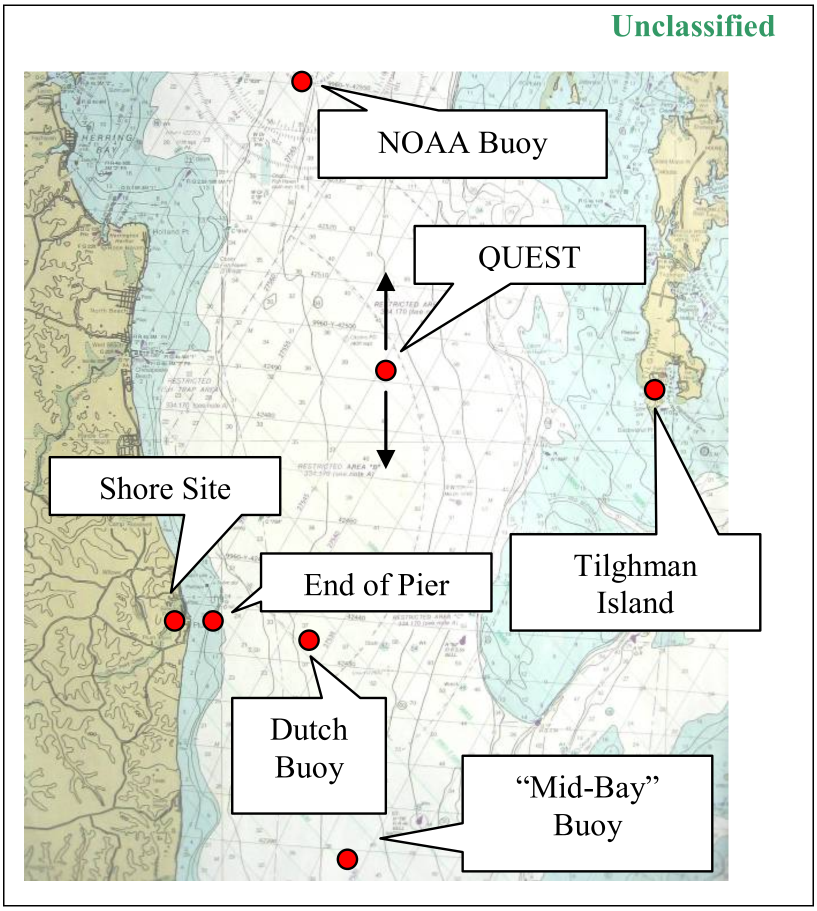


Figure 5-17: Diagram Showing Distribution of Met Stations.

5.7 SUMMARY AND OBSERVATIONS

SET-088/TG-51 executed a joint NATO IR trial during which radiometric measurements were taken of a variety of maritime targets and backgrounds. The trial represents "state-of-the-art" techniques in trial planning and execution. This was only possible by combining both the experience of several countries' IR measurement teams and their key instrumentation. When performing IR trials, it is critical to make spatially distributed weather observations over the operating area AND to have redundancy at key locations.

Radiometric IR measurements were made on many types of targets: a 77 m research ship, small craft (a speed boat and a jet ski), IR ship decoys and a small calibrated source that simulated the signature of an anti-ship cruise missile. In addition to these "target" measurements, second-order propagation effects were characterized, such as scintillation and refraction. All of the participating countries combined their results into a comprehensive database, which is available to all NATO Nations.

Chapter 6 – RECOMMENDATIONS

SET-088/TG-51 was an unqualified success. The Task Group enjoyed very strong participation from the vast majority of maritime NATO Nations. Each Nation assigned one or more delegates to the Task Group. The scientific quality of the delegates was extremely high.

The Task Group accomplished their objectives of advancing the state-of-the-art in the two major areas of IR ship signature research and maritime IR/EO propagation. A world-class measurement campaign was executed which was enabled only by the joint resources of all of the participating Nations. This trial has become widely known throughout the community as the "gold standard" for how future IR/EO experiments should be run. Valuable data was collected that supported the validation of complex computer simulations that can now be used more effectively by all countries for defence applications. All of the SET-088/TG-51 Nations benefited by leveraging both human capital and scientific instruments from the other Nations.

While this Task Group was very successful, the research of the Group has identified several areas of further research. This world-class team of scientists from the NATO Nations will continue their research in the follow-on Task Group SET-144/TG-79.

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REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	STO-TR-SET-088 AC/323(SET-088)TP/541	ISBN 978-92-837-0202-3	UNCLASSIFIED/ UNLIMITED

5. Originator

Science and Technology Organization
North Atlantic Treaty Organization
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title

Littoral Infrared Ship Self Defence Technology Studies

7. Presented at/Sponsored by

Final Report of Task Group SET-088/RTG-51.

8. Author(s)/Editor(s)	9. Date
Multiple	May 2014

10. Author's/Editor's Address	11. Pages
Multiple	44

12. Distribution Statement

There are no restrictions on the distribution of this document. Information about the availability of this and other STO unclassified publications is given on the back cover.

13. Keywords/Descriptors

Atmospherics	Modeling
Countermeasures	Radiometry
Infrared	Ship signature control
Littoral	Surveillance

14. Abstract

Task Group Number 51 (RTG-51/SET-088), titled "Littoral Infrared Ship Self Defence Technology Studies", started on 1 January 2004 and ended on 31 December 2008. This Task Group addressed the following aspects of littoral ship self defence: 1) The detection of anti-ship missiles in littoral environments; 2) The detection of small surface targets in littoral environments; 3) The upgrade and validation of the Naval Threat Countermeasure Simulator modeling and simulation code to include decoys and missile seekers; 4) Additional upgrade and validation of the SHIPIR modeling and simulation code; 5) The development of infrared ship signature specification guidelines; and 6) The study of infrared signature reduction techniques.

The main focus of the Task Group was a trial, SAPPHIRE (Ship and Atmospheric Propagation Phenomenon InfraRed Experiment.) The trial was conducted in the eastern United States in the Chesapeake Bay in June 2006.

Radiometric IR measurements were made on many types of targets: a 77 m research ship, small craft (such as a speed boat and a jet ski), IR ship decoys and a small calibrated source that simulated the signature of an Anti-Ship Cruise Missile (ASCM). In addition to these "target" measurements, second-order propagation effects were characterized, such as scintillation and refraction.

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ISBN 978-92-837-0202-3